SHAPLEY-AMES GALAXIES IN THE BLUE AND INFRARED

Sidney van den Bergh

Dominion Astrophysical Observatory, Herzberg Institute of Astrophysics, National Research Council of Canada, 5071 West Saanich Road, Victoria, BC, V9E 2E7, Canada

sidney.vandenbergh@nrc.gc.ca

Received ______________________; accepted ______________________

ABSTRACT

The Shapley-Ames Catalog of 1276 galaxies with B $<$ 12.5 is compared with the Sanders et al. all sky sample of the 629 galaxies with 60 μm flux density $>$ 5.24 Jy. The fraction of Shapley-Ames galaxies that are visible in the IR is found to increase from 0.006 for E and E/S0 galaxies to 0.384 for Sc galaxies. The subset of Shapley-Ames galaxies that are detected in the IR has a median blue luminosity that is $\sim$0.8 mag fainter than that of all Shapley-Ames galaxies. Most of this difference is due to the fact that late-type galaxies (which contain dust and hot stars) are systematically less luminous in blue light than are early-type galaxies. Within individual stages along the Hubble sequence no significant differences are found between the luminosity distributions in blue light of galaxies that were detected in the infrared and those that were not. However, our data show a puzzling exception (significant at 99.9%) for SBc galaxies. For reasons that are not understood Shapley-Ames SBc galaxies, that are visible in the IR, are more luminous in blue light than those SBc galaxies that are not detected in the infrared. An other peculiarity of the data is that Shapley-Ames Sc galaxies galaxies are (at 99.6% confidence) more luminous in blue light than objects of type SBc.

Subject headings: galaxies: statistics-galaxies: spiral

1. INTRODUCTION

Two decades ago Sandage & Tammann (1981) published *A Revised Shapley-Ames Catalog of Bright Galaxies* which contained photometry, and uniform morphological classifications, for 1276 galaxies with total apparent blue magnitudes brighter than B = 12.5, although the data become increasingly incomplete for B > 12.0. These observations may be compared to recent complete all sky infrared photometry of 629 galaxies with a total 60 μm flux density greater than 5.24 Jy by Sanders et al. (2003). Such a comparison of the Shapley-Ames Catalog with the data by Sanders et al. shows that 298 of these galaxies have both B < 12.5 mag and 60 μm flux > 5.24 Jy. It is the purpose of the present note to see how this sub sample of 298 galaxies visible in both the blue and in the infrared differs from the entire galaxy sample in the Shapley-Ames Catalog. The present work may be regarded as an update of a similar study by de Jong et al. (1984), which covered only 165 galaxies observed at 60 μm. It would be particularly interesting to test their conclusion that the rate of star formation in barred spirals is greater than that in normal spirals. The more extensive data that are now available should also allow one to firm up the conclusion by de Jong et al. that the fraction of infrared emitting galaxies depends on Hubble type in the sense that spiral galaxies are more likely to be infrared emitters than are ellipticals. All galaxy classifications and luminosities used in the present paper were drawn from *A Revised Shapley-Ames Catalog* (Sandage & Tammann 1981). In doing the statistics a galaxy classified as say Sb/Sc was counted as 0.5 Sb and 0.5 Sc.

2. MORPHOLOGY DISTRIBUTIONS OF GALAXIES

Table 1 shows a comparison between the frequency distributions of various galaxy types in the Shapley-Ames Catalog (Sandage & Tammann 1981, p. 91) [which are denoted SA] and the distribution of morphological types in the subset of Shapley-Ames galaxies that

were detected in the infrared by Sanders et al. (2003) [which is denoted by IR]. The most striking feature of these data (see Table 2) is that the fraction of galaxies that are detected in the infrared is a strong function of morphological type. Such an effect is expected because the 60 μm radiation from galaxies is dominated by emission from warm dust surrounding young hot stars. Only 0.6% of E + E/S0 galaxies in the Shapley-Ames Catalog were seen in the IR compared to 38.4% of Shapley-Ames Sc galaxies. [The single E galaxy in the sample that was detected in the IR is NGC 1275, which may actually represent the collision of a spiral and a giant elliptical (Baade & Minkowski 1954)].

A comparison between all Shapley-Ames galaxies, and the sub sample of those galaxies that were detected at 60 μm, shows that the median blue luminosity of the IR sub sample is ∼0.8 mag fainter than the median luminosity of all Shapley-Ames galaxies. The main reason for this difference is that late-type galaxies (which contain hot young stars that are able to heat dust) are systematically less luminous in blue light [see Figure 1 of van den Bergh (1997)] than early-type galaxies. However, the present data suggest that the truth might actually be a bit more subtle than this. Kolmogorov-Smirnov tests show no significant difference between the luminosity distributions in blue light of Sa and SBa, Sab and SBab, Sb and SBb, Sbc and SBbc galaxies that are (or that are not) detected in the IR. However, a K-S test does show that SBc galaxies that are visible in the infrared are (at the 99.7% significance level) more luminous in blue light than are those that were not detected in the IR. This result may also be seen in a different way by considering the contingency tables shown as Tables 3 and 4. Table 3 shows such a 2x2 contingency table in which Sc galaxies are split into objects that where detected (or not detected) in the IR and that are brighter (or fainter) than $M_B = -21.0$. A similar table for SBc galaxies is presented in Table 4. The latter contingency table yields a probability of less than 0.1% that the bright and faint SBc galaxies that are IR-bright were drawn from the same parent population of blue luminosities as those that are IR-dark. The observed difference is in the

sense that IR-bright SBc galaxies are more luminous than are IR-dark SBc spirals. (Little or no difference is seen between the IR bright and IR dark Sc galaxies in Table 3). The reason for the observed difference between IR bright and IR dark SBc galaxies is presently not understood.

The data in Table 5 show that 29% of all normal spirals were detected in the infrared, compared to only 21% of barred spirals. The data in this contingency table show that the difference in IR detection probability between S and SB galaxies is significant at the 99% level. This difference in the IR delectability of S and SB galaxies is almost entirely due to the fact that faint Sc galaxies are so much more likely to be detected in the IR than is the case for faint SBc galaxies. This difference is puzzling because the Sc and the SBc galaxies fainter than $M_B = -21.0$ have almost exactly the same mean luminosities in blue light. The difference in their IR properties might be due to either (1) faint Sc galaxies being dustier than faint SBc galaxies, or (2) to the dust in faint Sc galaxies being closer to the hot illuminating stars than is the case in galaxies of type SBc. Neither of these two alternatives appears very attractive.

3. FLUX DEPENDENCE OF GALAXY CHARACTERISTICS

The bi-variate luminosity function of galaxies (cf. Auriemma et al. 1977) can sometimes provide additional information on galactic evolution. However, a subdivision of data samples only provides additional insights for large samples. In the present case the sample of 298 Shapley-Ames galaxies in the infrared catalog of Sanders et al. (2003) may be divided into an IR bright sub sample of 157 galaxies with 60 μm flux ≥ 10.0 Jy, and an IR faint sub sample with 141 objects having 10.00 Jy $< f <$ 5.24 Jy. Inspection of the data (and comparison with Table 1) appears to show no obvious differences between the distribution of the IR bright and IR faint sub samples over Hubble type. Table 6 shows

the distribution of 60 μm IR radiation for Sc galaxies as a function of parent galaxy blue luminosity. The table has Chi^2 = 5.06 (with two degrees of freedom) yielding only an 8% probability that luminous Sc galaxies are more likely to be observed in the IR than are less luminous Sc galaxies. In this this respect Sc galaxies differ significantly from those of type SBc for which a strong dependence of IR luminosity on blue luminosity was found in Section 2. Table 7 clearly shows that this effect is entirely due to the striking difference in IR detections between bright ($M_B \leq -21.0$) and faint ($M_B > -21.0$) SBc galaxies. The reason for this enormous difference is not clear.

A comparison between the luminosity distributions of Shapley-Ames Sc and SBc galaxies shows that there are, relatively speaking, fewer faint Sc galaxies than faint SBc galaxies. A Kolmogorov-Smirnov test shows that this excess of faint SBc galaxies is significant at the 99.6% level. Posssibly this apparent difference in the luminosity distributions of Sc and SBc is due to a small systematic effect in the galaxy classifications by Sandage and Tammann. Alternatively very late-type dwarfs might be more prone to bar formation than galaxies of slightly earlier morphological types. Statistical weak support for the latter suggestion is provided by the observation that 8.5 out 20 (42%) of the Sm and Im galaxies (which are all intrinsically faint) in the Shapley-Ames catalog are barred, compared to only 24% barred objects among the Shapley-Ames galaxies of type Sc with ($M_B > -21.0$).

4. CONCLUSIONS

The luminosity of a galaxy at 60 μm is determined by (1) the rate of star formation, by (2) the amount of dust present in that galaxy and (3) by the relative distribution of hot young stars and the dust (Misiriotis et al. 2004). One would expect actively star forming late-type galaxies to be stronger IR emitters than inactive early-type galaxies.

This expectation is strongly confirmed by the data in Table 2 which show that the fraction of Shapley-Ames galaxies, that are observed in the IR, rises from only 0.6% among E + E/S0 galaxies to 38.4% for Sc galaxies. It is noted in passing that the very low frequency of IR emission among elliptical galaxies also suggests that the rate at which early-type galaxies swallow late-type spirals must presently be quiet low. The new data by Sanders et al. (2003) do not support the tentative suggestion by de Jonge et al. (1984) that the rate of star formation in barred spirals might be higher than that in normal spirals. In fact the more modern data suggest (at 99% confidence) that normal spirals are actually more likely to be visible in the IR than is the case for barred spirals. For all galaxy types (except SBc) the distributions of blue luminosities for all objects that are detected in the IR is statistically indistinguishable from that of those that are not detected in the infrared. However, a puzzling exception is provided by SBc galaxies that are unexpectedly faint in blue light. It turns out that such objects are much less likely to be IR emitters than is the case for Sc galaxies that are luminous in blue light. No reasonable explanation is found for this effect.

I should like to thanks Colin Borys and Doug Johnstone for their kind help with references to the literature on dust and infrared emission. Finally I express my thanks to the referee, Prof. T. de Jong, for impressing on me the importance of the bi-variate luminosity function of galaxies.

REFERENCES

Auriemma, C., Perola, G. C., Ekers, R., Fanti, R., Lari, C., Jaffe, W. J., & Ulrich, M. H. 1977, A&A, 57, 41

Baade, W. & Minkowski, R. 1954, ApJ, 119, 215

de Jong, T., Clegg, P. E., Soifer, B. T, Rowan-Robinson, M., Habing, H.J, Houck, J. R., Auman, A. A., & Raimond, E. 1984, ApJ, 278, L67

Misiriotis, A., Papadakis, I. E., Kylafis, N. D. & Papamastorakis, J. 2004 A&A (in press = astro-ph/0312258)

Sandage, A. & Tammann, G. A. 1981, *A Revised Shapley-Ames Catalog of Bright Galaxies*, (Washington: Carnegie Institution of Washington)

Sanders, D. B., Mazzarella, J. M., Kim, D.-C., Surace, J. A. & Soifer, B. T. 1984, AJ, 126, 1607

van den Bergh, S. 1997, *Galaxy Morphology and Classification* (Cambridge: Cambridge University Press)

.

.

This manuscript was prepared with the AAS LaTeX macros v5.2.

Table 1. Frequency distribution of Hubble types

Normal spirals			Barred spirals		
Type	IR	SA	Type	IR	SA
E + E/S0	1	173			
S0 + S0/a	6.5	142	SB0 + SB0/SBa	1	48
Sa + Sab	23.5	123	SBa + SBab	6.5	42
Sb + Sbc	71.5	187	SBb + SBbc	30.5	96
Sc	112.5	293	SBc	19	77
Scd + Sd	4	26	SBcd + SBd	0	8
Sm + Im	7	13	SBm + IBm	2	9
S	4	16	SB	0	5
Special	8	18			
Total	238	991		59	285

Table 2. Percentage of normal spirals detected at 60 μm

Type	IR detections
E + E/S0	1%
S0 + S0/a	5%
Sa + Sab	19%
Sb + Sbc	38%
Sc	38%

Table 3. IR detection frequency for luminous and faint Sc galaxies

Luminosity	IR detected	Not seen in IR
$M_B \leq -21.0$	47	74.5
$M_B > -21.0$	59.5	108

Table 4. IR detection frequency for luminous and for faint SBc galaxies

Luminosity	IR detected	Not seen in IR
$M_B \leq -21.0$	12.5	8.5
$M_B > -21.0$	6.5	47.5

Table 5. IR detection frequency for normal and barred spiral [a]

Type	S	SB
Detected in IR	237	59
Not detected in IR	581	226

Table 6. Correlation between 60 μm flux f and optical luminosity of Shapley-Ames for galaxies of type Sc

Blue luminosity	$f \geq 10.00$ Jy	$10.00 > f > 5.24$ Jy	f <5.24 Jy
($M_B \leq -21.0$)	31	16	74.5
($M_B > -21.0$)	27.5	32	108

Table 7. Correlation between 60 μm flux f and optical luminosity of Shapley-Ames for galaxies of type SBc

Blue luminosity	$f \geq 10.00$ Jy	$10.00 > f > 5.24$ Jy	$f <5.24$ Jy
$(M_B \leq -21.0)$	6	6.5	8.5
$(M_B > -21.0)$	3.5	3	47.5